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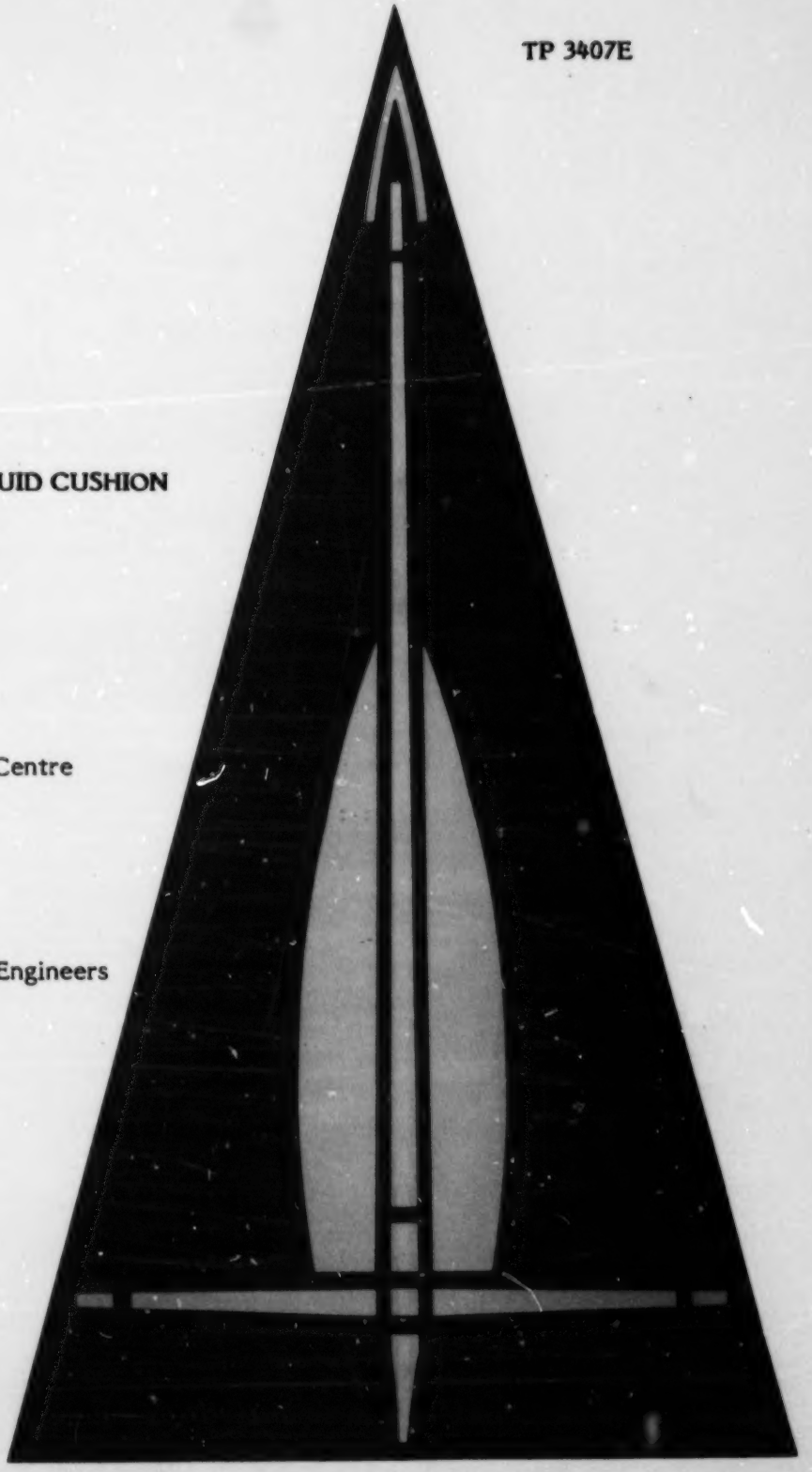
CONCEPTS FOR THE INTEGRATION OF A FLUID CUSHION INTO THE BOW OF A SHIP



Prepared for
Transportation Development Centre
Transport Canada

by German & Milne Inc
Naval Architects and Marine Engineers

January 1982

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17. Abstract

The Transportation Development Centre, Transport Canada, has initiated an ambitious six step program to exploit the potential of air cushion technology as applied to icebreaking.

This report suggests a criterion for examining icebreaker performance, considers the practicability of water and air cushions, and proceeds to the calculation of powering requirements for a conventional bow and an air cushion bow for various ice thickness. The superiority of the air cushion bow for the icebreaking mode is demonstrated, but this superiority decreases as ice thickness increases because the power required to clear rather than to break ice increases at a much greater rate.

Four design concepts are suggested, and a development program leading to the modification of a trawler for air cushion ice-breaking trials is outlined.

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17. Résumé

Le Centre de développement des transports, Transports Canada, a initié un programme en six étapes afin d'exploiter le potentiel du coussin d'air pour le déglaçage.

Ce rapport suggère un critère d'évaluation pour la performance d'un briseglace, considère l'application pratique des coussins d'air ou d'eau, et compare la puissance requise pour l'opération d'une proue à coussin d'air et d'une proue conventionnelle pour différentes épaisseurs de glace. La supériorité du coussin d'air pour la rupture de la glace est démontrée, mais cet avantage diminu lorsque l'épaisseur de la glace augmente, parce que la puissance requise pour la dispersion des blocs augmenterait beaucoup plus vite que celle requise pour la rupture uniquement.

Quatre concepts d'integration sont suggérés et un programme de développement est proposé qui verrait la modification d'un chalutier pour l'essai du concept.

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TABLE OF CONTENTS

1 INTRODUCTION 1

2 LITERATURE REVIEW 2

3 CRITERION FOR EVALUATION OF ICEBREAKING PERFORMANCE 3

4 CONCEPTUAL DESIGN PROPOSALS 4

4.1 General 4
4.2 Water Cushion 6
4.3 Air Cushion 8
4.4 Powering Estimates 8
4.4.1 For Air Cushion Bow 8
4.4.2 For Conventional Icebreaker 12
4.4.3 Example Vessel 12
4.4.4 Results of Commputations 13
4.4.5 Increasing Ship Size and/or Capability 16
4.5 Conceptual Design Proposals 19
A Retractable Bow 19
B Twin Hull Ship 21
C Platform and Tender 21
D Small Clearance Bow 25

5 PROPOSAL FOR FOLLOW-ON PROGRAM 26

5.1 Design Phase 26
5.2 Construction Phase 27

BIBLIOGRAPHY 28

TABLES

1 Cushion pressures required for various ice thicknesses 5

FIGURES

1 Typical Icebreaking Lines Applied to Barge Shaped Bow 7
2 Total Power V Speed For Various Ice Thicknesses (17 m Beam) 14
3 Figure of Merit V Speed For Various Ice Thicknesses (17 m Beam) 15
4 Figure of Merit V Speed For Various Ice Thicknesses (20 m Beam) 17
5 Relative Cushion Fan Power For Various Ice Thicknesses (20 m Beam) 18
6 Retractable Bow 20
7 Twin Hull Ship 22
8 Platform and Tender 23
9 Small Clearance Bow 24

APPENDICES

A Computer Program and Printout
B Proposal by Hovercraft Consultants Limited

CONCEPTS FOR THE INTEGRATION OF A FLUID CUSHION INTO THE BOW OF A SHIP

1 INTRODUCTION

In order to exploit the success achieved by the Canadian Coast Guard in the application of air cushion technology to icebreaking, the Transportation Development Centre, Transport Canada, has initiated an ambitious six step program, as follows:

1. Preliminary concepts definition. It is proposed to develop about three of the best ideas proposed for the integration of a fluid cushion in a ship bow.

2. Detailed analysis of one or more concepts, including experimental model studies, to establish the technical feasibility of an icebreaker with an integral fluid cushion bow.

3. Engineering design of integral fluid bow for an icebreaker.

   The prototype ship under consideration is a shallow draft light icebreaker of 1400 to 1700 tonnes displacement. The design ice rupture load is 1,000 kN at 5 knots.

4. Construction and testing of light icebreaker with an integrated fluid cushion bow.

5. Design of fluid bow for an Arctic class icebreaker.

6. Construction and testing of an Arctic class ice-breaker with a fluid cushion bow.

This preliminary concept study constitutes part of Step 1 of this program.

2 LITERATURE REVIEW

A literature search was carried out with the aid of the Canada Institute for Scientific and Technical Information and the Transport Canada Library. Very little information of value was obtained, but the review process was interesting and educational.

The most valuable papers were those by Decker[1] and Carter[2], which were used to calculate the dimensions of the cushion for various ice thicknesses. It seems that the advances in fluid cushion technology which will be required by this program are very considerable and, unfortunately, direct scaling from current practice is not possible. In consequence a simplistic approach is suggested, in which development is related to successful experiments and experience.

One important area on which published information is considered inadequate related to the profile of the ice sheet through which a vessel operating in polar ice must pass, and its surface roughness. Since this will have a considerable bearing on the practicability of the project, it is suggested that it should be investigated as soon as possible.

3 CRITERION FOR EXAMINING ICEBREAKER PERFORMANCE

The process of icebreaker operation involves, simply speaking, two modes. The first is the breaking mode, in which the ice field encountered is fractured by applying a vertical force to the ice sheet. The second, or clearing, mode involves moving the broken ice out of the path of the vessel.

A conventional icebreaker applies the vertical fracturing force to the ice sheet when the horizontal propelling force causes the stem of the vessel to ride up the ice edge. This results in part of the ship weight being supported by the ice. When this load reaches the supportable limit, the ice fails, the ship moves forward and the process repeats. If the propeller force is insufficient, or the ice too thick, then the vessel will not be able to apply the load necessary to fracture the ice and must resort to ramming, whereby the kinetic energy of the moving vessel is used to add an inertial force to the propelling force. Thus it can be seen that the larger the vertical force produced for a given horizontal (propelling) force, the more rapidly will the ship break ice. Consequently it seems reasonable to use the ratio of vertical force to horizontal force for a given form as a measure of the icebreaking capability of that form.

However, in assessing the merit of different alternatives, one must also consider their effectiveness and the resources used by each. This would eliminate the case of a device that could produce a pure vertical force for zero horizontal force, such as a non-propelled ACV, which would have an infinite force ratio, but not go anywhere. Ideally the final analysis would be on the basis of lifetime cost, since this would include the effects of equipment purchase, operation, maintenance, fuel utilization and vessel replacement, on the basis that alternative vessels perform the same functions. For the purpose of this study, it was not considered necessary to attempt this depth of comparison, since it would involve assumptions regarding parameters such as operating profiles and very preliminary construction cost estimates. The most suitable measure of merit is considered to be one that takes into account the energy resources expended in proceeding through given ice conditions in a set time. This may be expressed as:

u = energy/unit distance

and is expressed in terms of kilowatt-hours per kilometre traversed in level ice of a given thickness.

This is readily convertible, if desired, to units of fuel consumed, once an operating profile is established.

4 CONCEPTUAL DESIGN PLANS

4.1 GENERAL

Slow speed icebreaking by a fluid cushion is achieved by applying a pressure to the upper surface of the ice equal to or greater than the pressure of the water at its lower surface. Provided that this pressure is applied over an appropriate area, the ice will then collapse under its own weight. In air cushion icebreaking an air cavity under the ice may be achieved and leave the ice completely unsupported.

The applied pressure will correspond to the ice thickness (see Table 1), and the area of cushion required may be calculated from formulae suggested in references 1 and 2, which give similar results.

The problems associated with operating in the Arctic are essentially the same as for operations in the St. Lawrence and Great Lakes except the scale is larger. Ice thicknesses are greater, ice ridges are higher and the average temperatures are lower. However the same problems of low temperature operation remain, icing, material suitability and maintenance being the prime considerations. In the Arctic operations are usually much more remote from base facilities, and these may well be less adequate than in the south. It will be virtually impossible to carry out major maintenance en route, for example replacement of a damaged skirt segment, unless early consideration is given to the problems and appropriate equipment and facilities provided. The criteria for successful Arctic operation must be concerned with simplicity and reliability.

Increased pressure means -

- Stronger (thicker) skirt material and attachments
- A harder cushion
- Reduced ability to follow contours (higher leakage)
- Greater wear
- A more serious spray suppression problem

The ACV to date has been essentially an over water vehicle with some capability to operate over land and to negotiate obstacles. In consequence, skirt design and development has been related almost entirely to over water operation, and it is possible that operation over ice may introduce new factors. Clearly the simplest possible skirt design will be necessary in order to achieve maximum reliability and maintainability under the severe environmental conditions, and particularly if the system is to be retractable. A study of skirt designs and materials will be essential.

TABLE 1

CUSHION PRESSURE REQUIRED FOR VARIOUS ICE THICKNESSES

ICE THICKNESS		PRESSURE - lb/in^2		PRESSURE - kPa	
FT	M	Fresh Water	Salt Water	Fresh Water	Salt Water
1	0.30	0.43	0.44	2.96	3.03
2	0.61	0.87	0.90	6.00	6.21
3	0.91	1.30	1.34	8.96	9.24
4	1.22	1.73	1.78	11.93	12.27
5	1.52	2.17	2.24	14.96	15.44
6	1.83	2.60	2.68	17.93	18.48
7	2.13	3.03	3.12	20.89	21.51
8	2.44	3.47	3.57	23.93	24.62
9	2.74	3.90	4.02	26.89	27.72
10	3.05	4.34	4.47	29.92	30.82

Mass Density of Fresh Water 0.43 lb/in^2, Salt Water 0.44 lb/in^2. Specific Gravity of Fresh Water 1.00, Salt Water 1.03

Pressures quoted are for water depths equal to ice thickness, and give an overpressure of about 10%.

4.2 WATER CUSHION

Consideration of a liquid cushion in connection with this project appears to be deviating from the exploitation of results already achieved with an air cushion. However some time has been spent on consideration of the subject.

Although a water cushion has been used successfully to move cargo pallets over smooth surfaces, this device was simple, and used low pressure water which was introduced at the centre and flowed outwards to the periphery . No reference to a peripheral water cushion has been found, and skirts have not been used with water so far as is known.

Because of the different media involved, water, air and ice, and their widely differing physical characteristics, it is difficult to visualize a practical liquid cushion. The curtain principle used by Cockerell to supply and contain an air cushion beneath a surface craft could probably be duplicated with a liquid, and, because of the higher density, a very much lower jet velocity would be required to maintain the curtain, assuming the same dimensional parameters. This would be true in the static case, but in the dynamic case, operating over an ice/water surface with rapidly changing contours, there would be serious difficulty in maintaining cushion pressure, and the movement of the liquid within the cushion would create momentum and inertia problems.

Elimination of the curtain by a plenum chamber system would not appear to reduce the problem which requires the maintenance of a head of water over a considerable area and its movement across a surface of ice and water which is exposed to air at atmospheric pressure. Maintenance of an adequate flow would be quite impractical.

Water curtains have been used to contain an air cushion, for example to provide forward and aft seals on the Hughes XHS-1 Hydrostreak solid sidewall craft of 1959. However, water curtains have not been pursued, probably because of the additional power requirements. It may be worth considering water curtains for an air cushion icebreaker, but it is recommended that this should be a separate development for possible use if a mechanical skirt system should prove impractical. It is suggested that further enquiries about experience and reasons for absence of further development should be made.

Water might be used as a dowsing system, which has been shown to reduce friction, and streamed or jetted under an icebreaking bow. However, without any sort of containment to maintain pressure, a satisfactory film could not be obtained, since the contours of bow and ice will never be the same, and the gain will be related solely to the wetting of the ice surface. This could not be termed a liquid cushion.

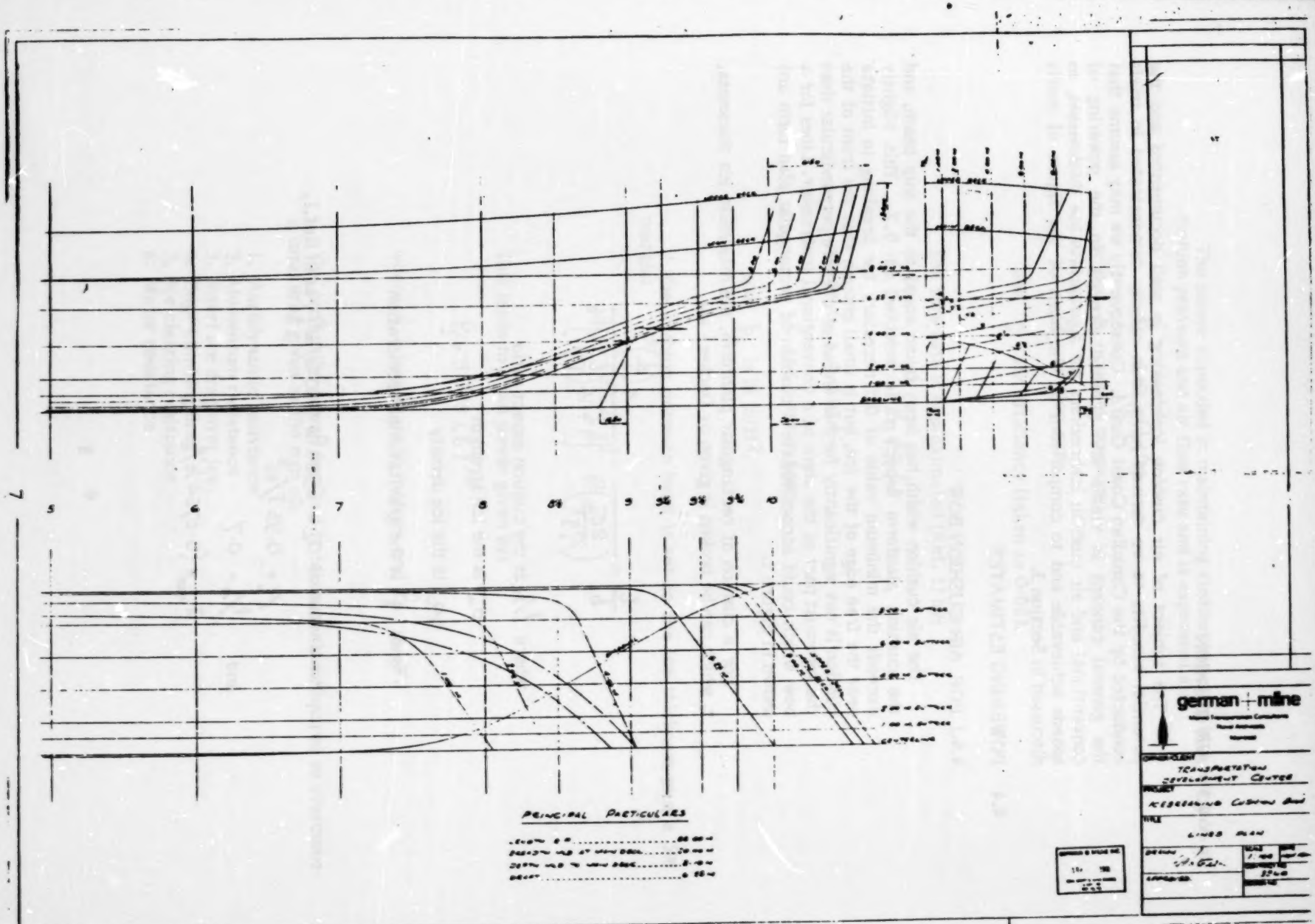


FIGURE 1 Typical icebreaking lines applied to barge shaped bow

4.3 AIR CUSHION

The subject of air cushion icebreaking is well documented and the potential benefits to be derived have been clearly demonstrated in trials conducted by the Canadian Coast Guard. Consequently we may assume that the general concept is viable and proceed directly to the powering of conventional and air cushion icebreakers for appropriate ice thicknesses, to speeds achievable and to comparisons on the basis of the figure of merit discussed in Section 3.

4.4 POWERING ESTIMATES

4.4.1 FOR AIR CUSHION BOW

The air cushion width has been taken equal to the ship beam, and the cushion planform aspect ratio selected at 0.7. This slightly exceeds the minimum value of 0.5 necessary for breaking to initiate near the free edge of the ice, but is small enough that the front of the cushion is not significantly further ahead of the fore perpendicular than the foremost part of the stem of a conventional icebreaker. Lines for a bow which could accommodate a cushion of rectangular plan form are shown in Figure 1.

For a cushion of rectangular planform, the maximum ice thickness, t, which can be broken is given by Decker[1] as:

$$\frac{t}{b} = \frac{1}{\left(\frac{2\sigma_u}{\rho_i g t}\right)^{1/2}} \cdot \frac{4\left(\frac{l}{b}\right)^2}{\left[1+16\left(\frac{l}{b}\right)^4\right]^{1/2}}$$

where l/b is the cushion aspect ratio

σ_u is the ice strength

ρ_i is the ice density

and g is the gravitational acceleration

For a value of $\sigma_u = 690\,kPa$, $(100\,lb/in^2)$, as in Ref.1,

$\rho_i = 0.93\,t/m^3$

and $l/b = 0.7$

$t_{max} = (0.0724\,b)^2$

The power expended in maintaining cushion pressure is a function of cushion pressure and air flow rate and is expressed as:

$$P_f = 1.15 p_c Q_c / \eta$$

where p_c = cushion pressure

Q_c = air flow rate

and η = fan efficiency (taken as 0·82).

The flow rate is approximated (Ref. 1) by:

$$Q_c (ft^3/s) = 27.3 K_a \sqrt{p_c} l b$$

where C_a = 0·0024

l and b are in feet

and p_c is in lb/ft^2.

If the cushion pressure head is set to the ice thickness plus a 5% margin:

$$p_c = 1.05 \rho_i g t$$

This leads to a fan power given by:

$$P_f = 3.778 l b t^{1.5}$$

where l, b and t are in metres, and P_f in kW.

The propulsion power required is taken as that required to overcome a total drag given as the sum of:

1. Aerodynamic resistance
2. Momentum resistance
3. Interface drag over ice.
4. Edge climbing drag
5. Ice clearing resistance
6. Water resistance

The first two elements are relatively small. They are approximated (Ref. 1) by:

$$R_1 = K_1 V_K^2 C_{DS} S_F$$

where K_1 = a coefficient (value dependent on the units employed)

V_K = speed

C_{DS} = drag coefficient

and S_F = frontal area (approximately by $b^2/2$).

This reduces to:

$$R_1 = (0.55 \times 10^{-4})\, b^2 V_K^2$$

where R_1 is in kilo Newtons

b is in metres

and V_K is in knots.

Also: $R_2 = K_2 V_K Q_c$

$= (0.2 \times 10^{-3})\, l\, b\, V_K\, t^{1/2}$

where R_2 is in kilo Newtons

l, b and t are in metres

and V_K is in knots.

From Reference 1, the interface drag over ice is given by:

$$R_3 = \left[\frac{K_W W}{C_Q^{1.5}} \cdot 0.05 + \left(\frac{q_a}{p_c}\right)^{3/4}\right]$$

where $C_Q = 0.0024$

W = total cushion bearing force (= p_c lb)

and q_a = dynamic pressure of air

This can be expressed as:

$$R_3 = \ell b t \left[0.06104 + 0.000335 \left(V_K^2/t\right)^{3/4}\right]$$

where ℓ, b and t are in metres

and V_K is in knots.

The edge climbing drag is the reaction produced when the cushion pressure acts on the free edge of the ice sheet. This is expressed as:

$$R_4 = p_c b t$$

The ice clearing drag is that due to the vessel hull behind the cushion having to move the broken ice out of its path. There is not much analytical basis on which to develop a reliable resistance predictor equation for this mode of operation. It is known, however, that an icebreaker makes significantly better speed through a broken ice field than through an unbroken field of the same thickness.

From the limited data available an equation based on the performance of the ALEXANDER HENRY (Ref. 3) has been developed and can be expressed as:

$$R_5 = \left[28.15 + 2.481 \left(V_K/t^{1/2}\right)\right] B t^2$$

where B is the ship's beam in metres.

It should be noted that the ALEXANDER HENRY has a poor icebreaking form when compared with other icebreakers (Ref. 3), and therefore this element of the drag may well be less than that indicated by this equation.

The water resistance is a relatively minor element in the total drag in ice and is approximated by:

$$R_6 = K_3 \Delta^{2/3} V_K^2$$

where K_3 is selected according to the ship proportions (Ref. 1)

and Δ is the ship's displacement

4.4.2 FOR CONVENTIONAL ICEBREAKER

The drag in ice is based on the Kashteljan Equation[4] for icebreaker resistance in ice. By assuming a typical hull form with good icebreaking characteristics, a resistance equation is approximated by:

$$R_7 = 2.4Bt + 49.2Bt^2 + 1.3B^{1.65}tV_K$$

In addition to this, the drag on the conventional icebreaker will also include the water drag (R_6).

The total drag for each type of craft is converted to power required by assuming twin screw operation and a thrust/power relation as given by Milano[5]. The total power for the air cushion bow vehicle is taken to include the fan power requirement.

4.4.3 EXAMPLE VESSEL

For study purposes, the vessel size is taken to be that of a typical small icebreaker intended for river and Great Lakes service.

For the purpose of comparison, particularly in the graphs, ice thickness has been quoted in feet. This is to permit direct relation to the classification of icebreakers where, for example, Class 3 is generally accepted as meaning that the ship can maintain a steady speed in a uniform icefield 3 ft thick.

The CCGS ALEXANDER HENRY, with which some air cushion tests have been performed, served as a starting point. This vessel has a relatively poor icebreaking form and is capable of breaking about 0.3 m (1 ft) of ice in continuous motion with an installed power of 2640 kW. A good icebreaking form with the same beam and power should break about 0.5 m ice at about 3 kts. The CCGS PIERRE RADISSON with about 10,000 kW installed power and a beam of 20 m is capable of breaking about 0.9 m of ice in the continuous mode. Selecting a size between these two, approximately Arctic Class 2, was considered suitable for possible construction and application, as well as being a reasonable advance from previous tests without being a quantum leap into unknown regions.

The vessel dimensions would be approximately:

Length, L_{BP}	75.0 m
Beam, B	17.0 m
Draft, T	5.3 m
Depth, D	6.8 m

A total power level of 7,000 kW is selected at this stage although it exceeds the minimum requirement for an Arctic Class 2 vessel. This is based on the results obtained from the drag computations and on the space limitations of a vessel of this size.

The cushion would be nominally of the same beam as the ship (17 m) and of a length of about 12 m. The computations show that for a cushion of this size, the maximum ice thickness that can be broken is about 1.5 m requiring a fan power of about 1,400 kW. However, the drag in broken ice of this thickness would require a propulsion power of about 20,000 kW at low speeds. With a total installed power of 7,000 kW, a continuous low speed operation may be maintained in about 1.0 m ice (over 3 ft) with the fan consuming about 800 kW of that total. The load on the ice at the pressure for this thickness (1.0 m) and for a cushion of this rectangular planform would be about 2,000 kN.

This buoyant force on the fore end of the vessel would require a ballast tank of about 200 t capacity or an equivalent means of neutralizing the trim that would result from such a force, since the trim would be of the order of 1.5 m on a vessel this size. The easiest solution would be to install ballast tanks forward over the cushion. A pair of wing tanks, each about 12 m (long) x 6 m (wide) x 1.5 m (high) would accommodate the maximum cushion buoyancy in normal operation. The loss of buoyancy due to lowering of the water level in way of the cushion would be small due to the narrowness of the hull region affected, but would provide some benefit in countering the cushion buoyancy. In the event of a sudden loss of cushion pressure, the large width of the bow portion above the nominal waterline would prevent excessive trim by the head and the ballast tanks could easily be dumped if necessary.

4.4.4 RESULTS OF COMPUTATIONS

The equations for drag and powering have been assembled into a simple computer program and the results for an example vessel are shown in Figures 2 and 3.

As seen in Figure 2, the power required at a given speed is significantly greater for the conventional vessel than it is for one with an air cushion bow. The advantage of the latter increases as speed of operation is increased. Figure 3 is a plot of the measure of merit, u, as a function of speed and ice thickness. It shows that the value of u for the conventional vessel is approximately twice that for the air cushion ice bow. Since a smaller value of u indicates a lower energy utilization rate, it may be concluded that the fuel consumption is halved by use of the air cushion ice bow.

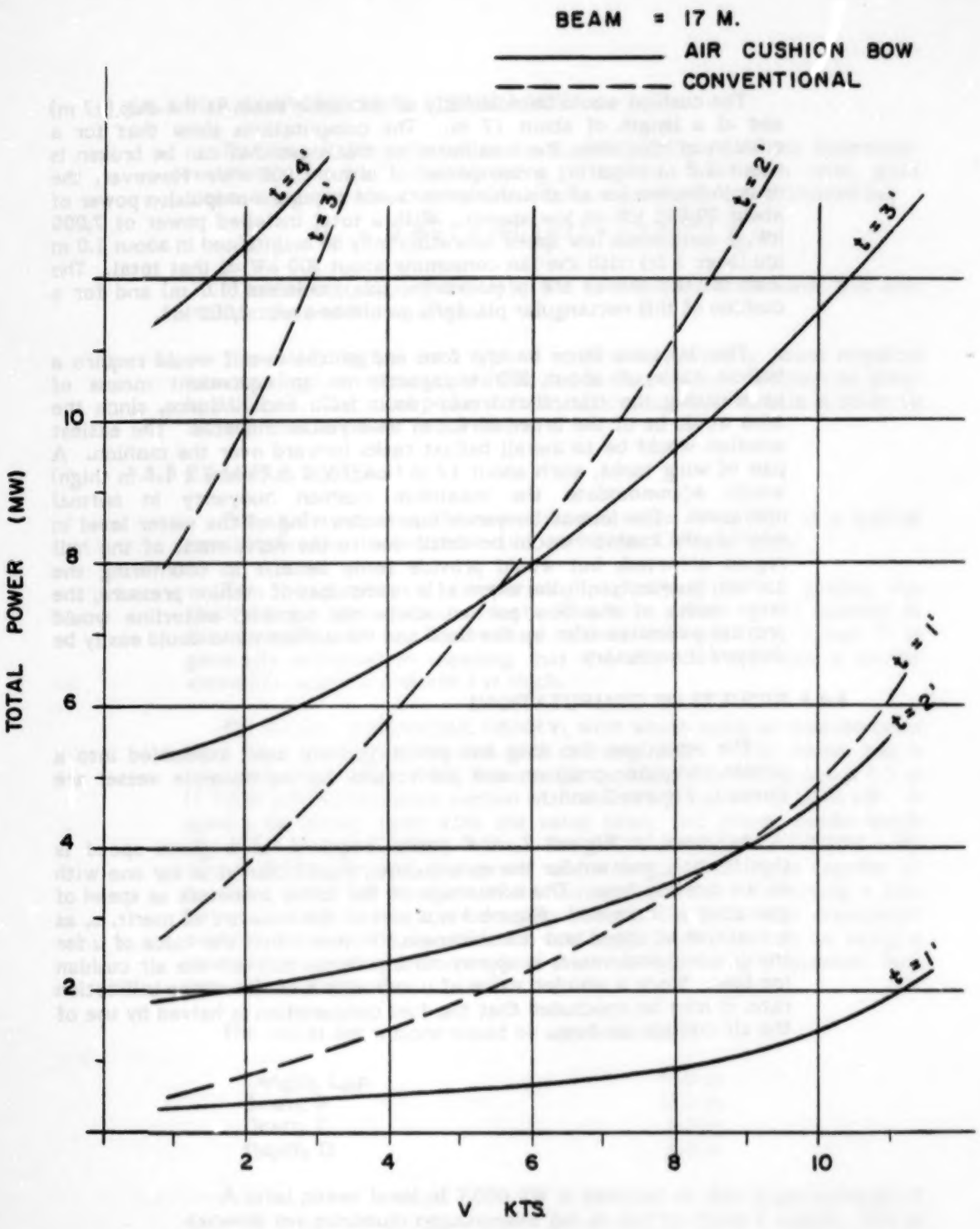


FIGURE. 2 TOTAL POWER V SPEED FOR VARIOUS ICE THICKNESSES

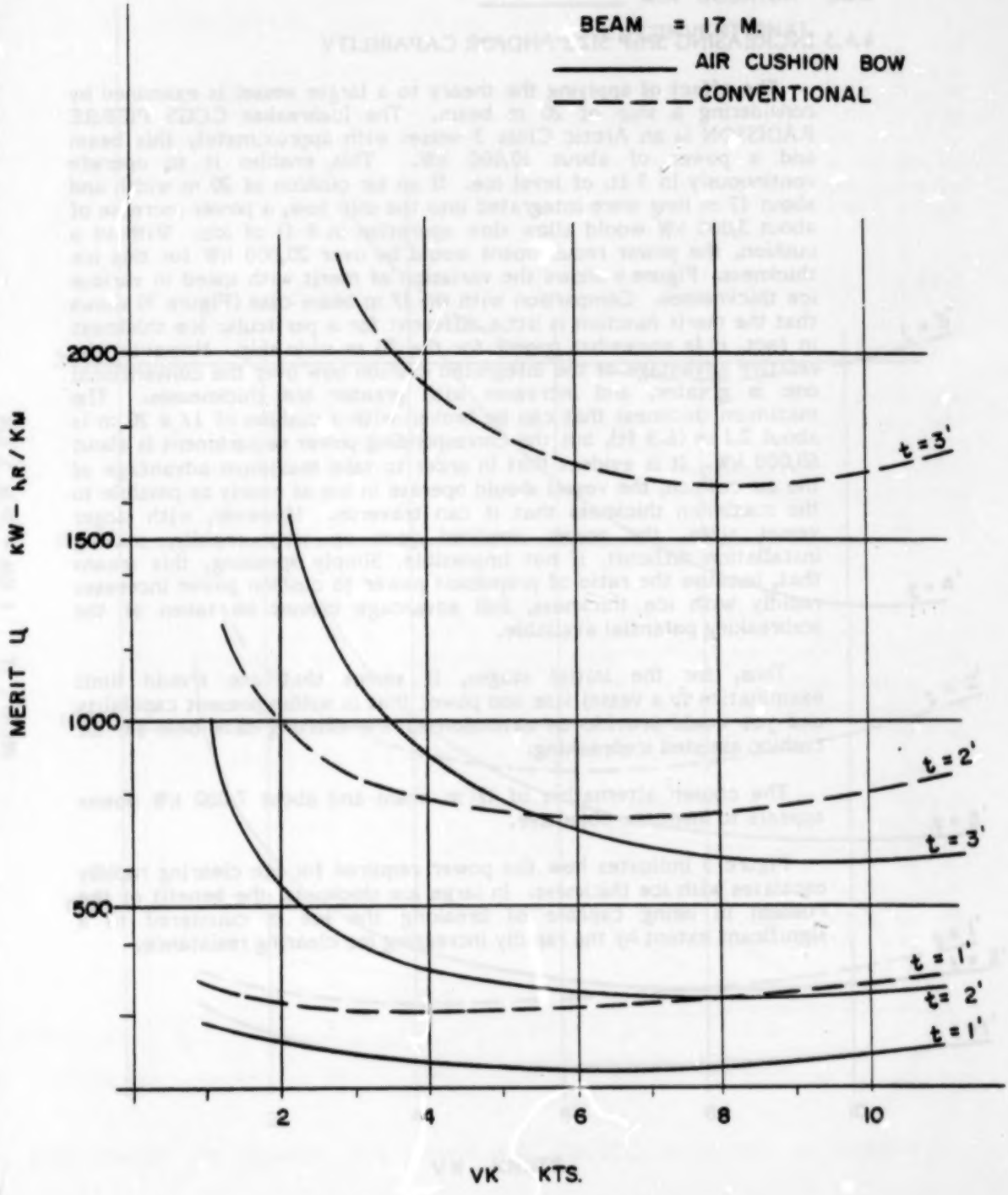


FIGURE. 3 FIGURE OF MERIT V SPEED FOR VARIOUS ICE THICKNESSES

4.4.5 INCREASING SHIP SIZE AND/OR CAPABILITY

The effect of applying the theory to a larger vessel is examined by considering a ship of 20 m beam. The Icebreaker CCGS PIERRE RADISSON is an Arctic Class 3 vessel with approximately this beam and a power of about 10,000 kW. This enables it to operate continuously in 3 ft. of level ice. If an air cushion of 20 m width and about 17 m long were integrated into the ship bow, a power increase of about 3,000 kW would allow slow operation in 4 ft of ice. Without a cushion, the power requirement would be over 20,000 kW for this ice thickness. Figure 4 shows the variation of merit with speed in various ice thicknesses. Comparison with the 17 m beam case (Figure 3) shows that the merit function is little different for a particular ice thickness in fact, it is somewhat poorer for the 20 m wide ship. However, the relative advantage of the integrated cushion bow over the conventional one is greater, and increases with greater ice thicknesses. The maximum thickness that can be broken with a cushion of 17 x 20 m is about 2.1 m (6.9 ft), but the corresponding power requirement is about 60,000 kW. It is evident that in order to take maximum advantage of the air cushion, the vessel should operate in ice as nearly as possible to the maximum thickness that it can traverse. However, with larger vessel sizes, the power required goes up very rapidly, making installation difficult, if not impossible. Simply speaking, this means that, because the ratio of propulsion power to cushion power increases rapidly with ice thickness, full advantage cannot be taken of the icebreaking potential available.

Thus, for the initial stages, it seems that one should limit examination to a vessel size and power that is within present capability and yet would provide an extension to the existing data base for air cushion assisted icebreaking.

The chosen alternative of 17 m beam and about 7,000 kW power appears to meet the objective.

Figure 5 indicates how the power required for ice clearing rapidly escalates with ice thickness. In large ice thickness, the benefit of the cushion in being capable of breaking the ice is countered to a significant extent by the rapidly increasing ice clearing resistance.

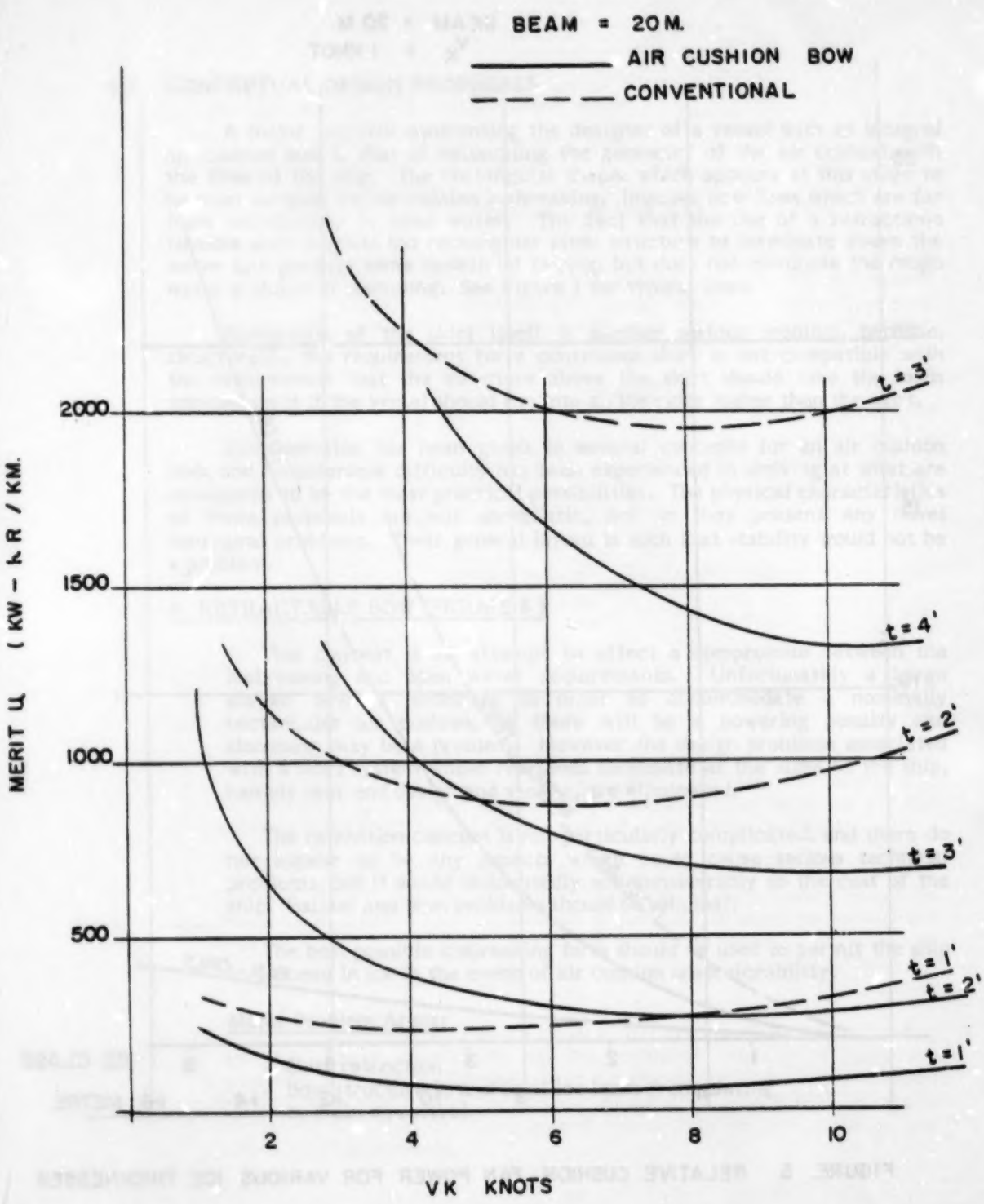


FIGURE. 4 FIGURE OF MERIT V SPEED FOR VARIOUS ICE THICKNESSES

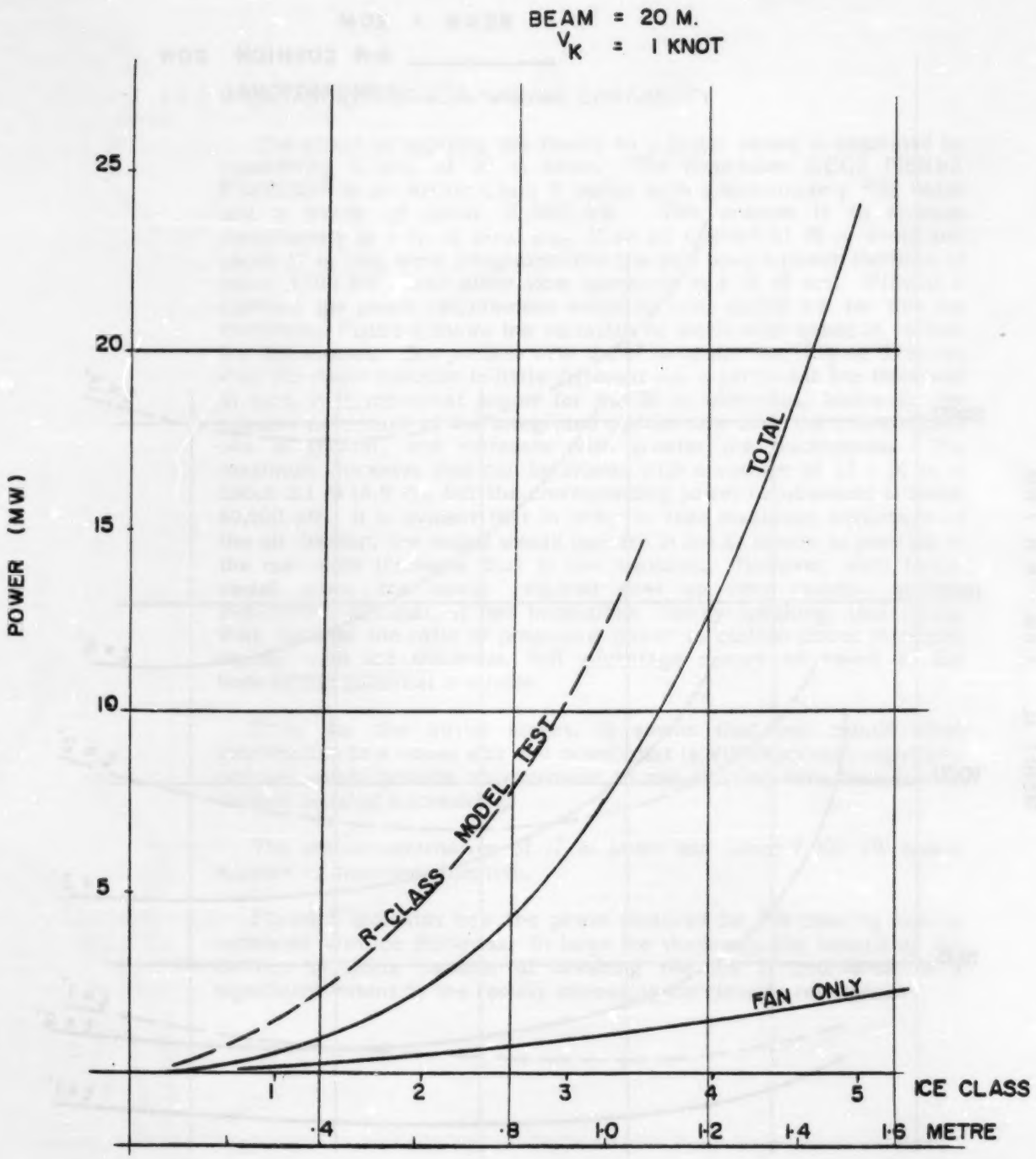


FIGURE. 5 RELATIVE CUSHION FAN POWER FOR VARIOUS ICE THICKNESSES

4.5 CONCEPTUAL DESIGN PROPOSALS

A major problem confronting the designer of a vessel with an integral air cushion bow is that of reconciling the geometry of the air cushion with the lines of the ship. The rectangular shape, which appears at this stage to be most suitable for air cushion icebreaking, imposes bow lines which are far from satisfactory in open water. The fact that the use of a retractable flexible skirt permits the rectangular steel structure to terminate above the water line permits some beneficial fairing, but does not eliminate the rough water problem of slamming. See Figure 1 for typical lines.

Retraction of the skirt itself is another serious problem, because, structurally, the requirement for a continuous skirt is not compatible with the requirement that the structure above the skirt should take the loads imposed on it if the vessel should run into an ice ridge higher than the skirt.

Consideration has been given to several concepts for an air cushion bow, and considerable difficulty has been experienced in arriving at what are considered to be the most practical possibilities. The physical characteristics of these proposals are not unrealistic, nor do they present any novel structural problems. Their general layout is such that stability would not be a problem.

A RETRACTABLE BOW (FIGURE 6)

This concept is an attempt to effect a compromise between the icebreaking and open water requirements. Unfortunately a barge shaped bow is necessary in order to accommodate a nominally rectangular air cushion, so there will be a powering penalty and slamming may be a problem. However the design problems associated with a skirt system whose rear ends terminate at the sides of the ship, namely rear end design and sealing, are eliminated.

The retraction concept is not particularly complicated, and there do not appear to be any aspects which could cause serious technical problems, but it would undoubtedly add considerably to the cost of the ship. Ballast and trim problems should be minimal.

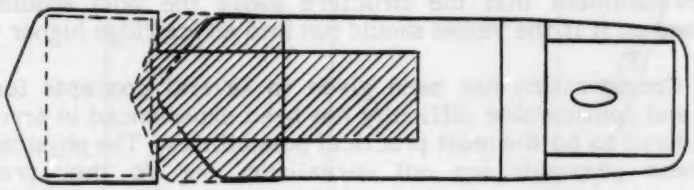
The best possible icebreaking form should be used to permit the ship to proceed in ice in the event of air cushion unserviceability.

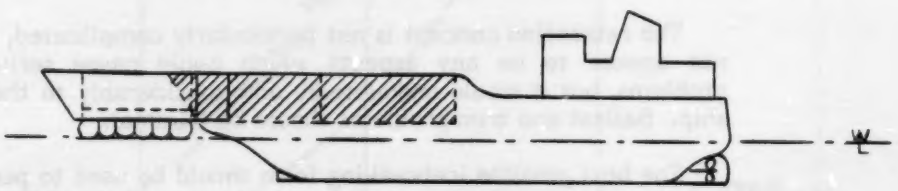
Major Problem Areas:

- Skirt retraction
- Bow structure (transfer of ice loads from plating to main structure)

FIGURE 6 RETRACTABLE BOW

Shaded area of structure, which contains the air cushion and ancillaries, is extended forward for air cushion deployment.





B TWIN HULL SHIP (FIGURE 7)

The geometry of a twin hull ship lends itself quite well to the accommodation of an air cushion. In addition, slamming is less likely to occur, and the possibility can be further reduced if fore and aft trimming to provide an automatic wave following mode is fitted.

Trimming may not be a serious problem with a catamaran, but with a SWATH ship (small waterplane area), trim is a matter which requires constant attention, and trimming to compensate for the buoyancy of the air cushion would, in all probability, be critical, particularly in the case of a sudden loss of cushion pressure. Ballast should be arranged so that it can be dumped in emergency.

Another, as yet unpublished, study for TDC indicates that a SWATH icebreaker will have a significantly higher ice transit speed than a conventional monohull icebreaker for the same power, with or without air cushion. However, it must be appreciated that ice is not cleared, only broken, and that following ships will not find a clear path.

Major Problem Areas:

- Skirt retraction
- Bow structure
- Cushion compartment closure
- Air cushion ballast and trim system (SWATH SHIP)

C PLATFORM AND TENDER (FIGURE 8)

The trials carried out with the ICEATER I in combination with the CCGS ALEXANDER HENRY, CCGS GRIFFON, MV IMPERIAL ST-CLAIR and tug THUNDER CAPE have demonstrated quite clearly the efficacy and versatility of the air cushion icebreaking bow platform.

If air cushion bow attachments of appropriate capability could be constructed and maintained in the sea areas in which they would be required to operate, suitable design would permit them to be utilized with any ice strengthened vessel of adequate power. Provision of special icebreakers with integral air cushion bows would then be unnecessary.

Even if a special ship which could either push or carry an air cushion platform were considered, all the problems relating to open sea operation and skirt retraction could be eliminated. In addition, since the platform would move vertically independent of the ship, it would not affect ship trim or stability, and would carry its own powering and ballasting requirements.

FIGURE 7 TWIN HULL SHIP

Either a catamaran or a SWATH ship would be appropriate for this concept. The cushion extends beyond the hulls or struts and retracts into shaded area.

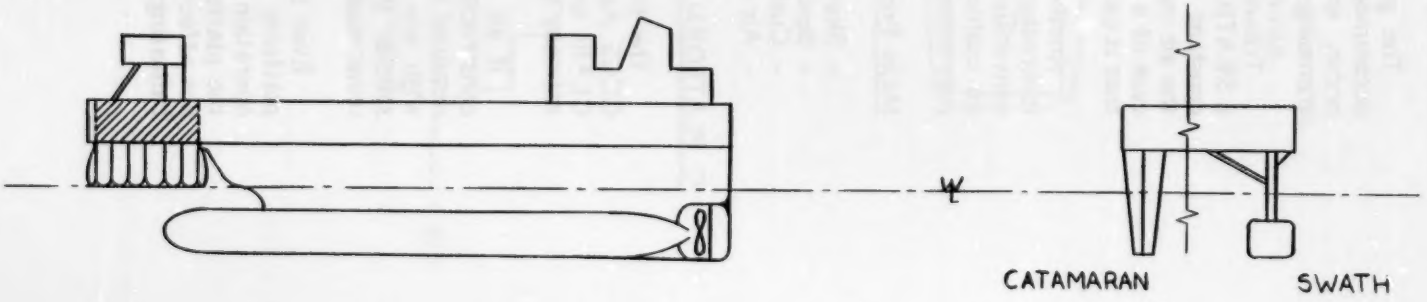
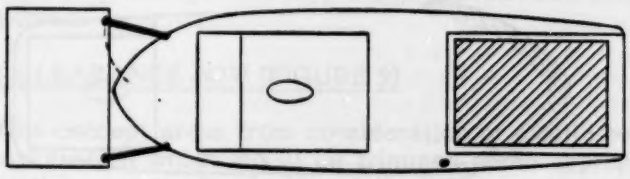


FIGURE 8 PLATFORM AND TENDER

Vessel has a tailgate through which the air cushion platform is deployed and recovered. Shaded area indicates stowed location. Platform is attached to bow of tender by two pin-jointed booms and a centre point restricting lateral motion.



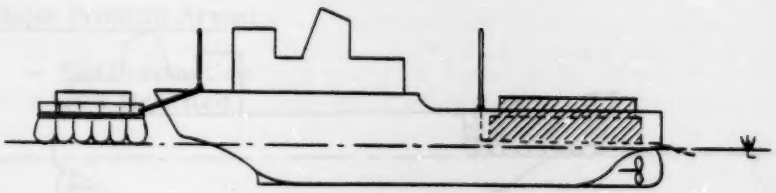
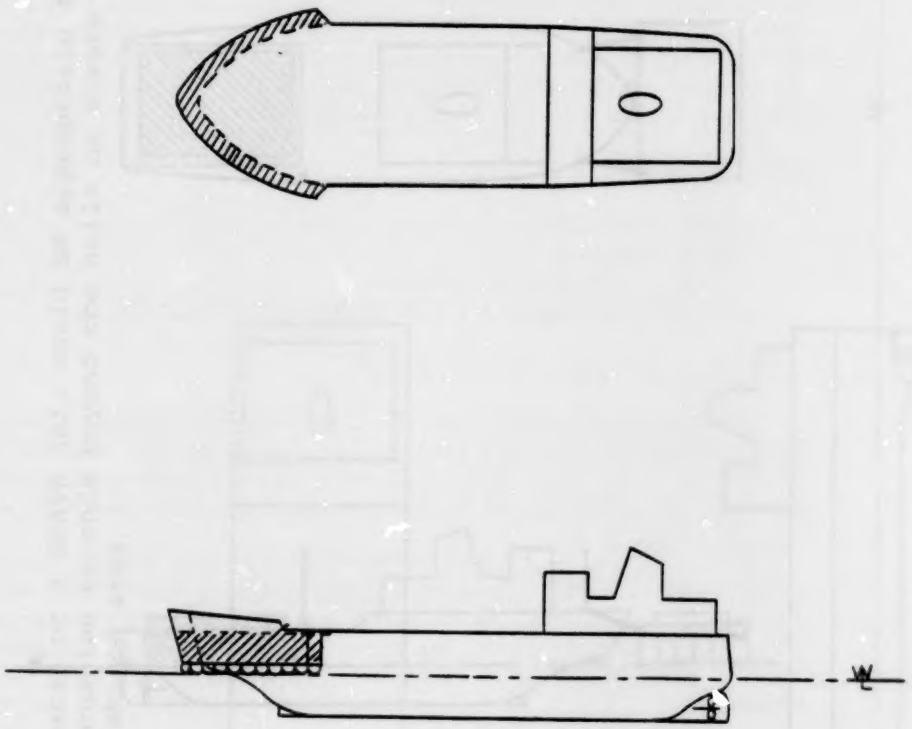


FIGURE 9 SMALL CLEARANCE BOW

Cushion retracts into shaded area.



The parent ship suggested for a platform and tender concept is essentially an ice strengthened tender with deck space to accommodate the air cushion platform when it is not required or for maintenance. Access to this compartment would be by a combination door/ramp, as in landing craft but at the stern. The platform would be winched out and in and around the ship.

Although the platform and tender may be regarded as separate items, they do, together, form an icebreaking system of which the platform, which becomes an air cushion bow, is an integral part.

The only problem area, which is not considered major, relates to the mating of the air cushion bow attachment and the ship - provision of a suitable yoke and attachment points.

Economically and operationally the air cushion bow attachment must be considered.

D SMALL CLEARANCE BOW (FIGURE 9)

This concept arose from consideration of a solid peripheral wall for the air cushion which would be trimmed to an appropriate gap height above the mean ice level. Hopefully the higher bumps and ridges would be skimmed off. Such a system, although very attractive from structural and maintenance viewpoints, would evidently require a sophisticated trim system to be effective.

As a compromise, it is suggested that a solid peripheral screen, essentially a second, false bow, should be provided to protect a flexible skirt deployed behind it. Clearance of the protective bow would be less sensitive, since a flexible seal would be provided, and only the lower portion of the skirt would be exposed. The solid bow would still be expected to skim off the ice above its clearance height.

Major Problem Areas:

- Skirt retraction
- Bow structure

5 PROPOSAL FOR A FOLLOW-ON PROGRAM

Since there are a number of potentially difficult problems to be solved, a simple step by step program is recommended. However, it is believed that the program suggested below could lead to the design of an integral air cushion bow for addition to a selected ship being completed during FY 1982-83. This would permit modification work to be put in hand with a view to trials during the winter of 1983/84, providing that decisions and financial provisions are made which would allow the program to proceed without delays.

5.1 DESIGN PHASE

i Testing to determine the behaviour and, hopefully, the optimum configuration for the air cushion/ship stem combination.

Discussions have already been held with the National Research Council Low Speed Aerodynamics Laboratory with a view to using the flow visualization water tunnel to examine air cushion behaviour for various cushion and bow shapes. It has been extablished that the tunnel runs satisfactorily with a free water surface, and the laboratory is setting up a simple model test to establish the feasibility of the approach. The general opinion is that useful information will be obtained.

No charge is being made for the preliminary work now in hand. If a program is approved, the per diem cost will be $330.00 for the tunnel and operator, and $183.00 plus 100% overhead for senior professional staff, in this case probably Mr. R.H. Wickens.

The details of a program will not be established until the feasibility has been determined, but, as a first stage, a very simple experiment in which a uniform ice field is represented by a plexiglass sheet is visualized. No attempt will be made to simulate icebreaking. However, it is hoped that, as experience is built up, it may be possible to model the icebreaking mode and attempt to optimize the ice clearing aspect. This, of course, could be a very profitable exercise.

ii Investigation of air cushion skirt systems

At our request, Hovercraft Consultants Limited have submitted a comprehensive proposal to advise on the skirt and cushion design. The assistance which they would provide, together with costs, is included in their submission (Annex B).

This work could start as soon as a preliminary decision can be made on the basic cushion/stem configuration. The small clearance bow is recommended for the first trials.

iii Design of the Integrated Bow System

This will tend to be an iterative process, starting with the selection of one of the concepts which have been suggested. The configuration will be influenced by the water tunnel tests, and the detail design by the skirt design proposals and the vessel selected for conversion. Consequently it will be necessary to decide on the trials ship at an early stage and to make preliminary arrangements for charter or purchase.

A trawler of 1000 to 1500 tonnes would appear to be the best choice for the following reasons:

- The size is appropriate for initial trials
- They are powered for high resistance at low speed
- They have trim systems with a large range, considerable stern trim being required to give adequate directional stability when trawling.
- They have a fish room (hold) which could accommodate the machinery required for the air cushion.
- The stability range is large.
- At the present time suitable vessels are readily available.

We would be prepared to select an appropriate vessel and arrange for charter or purchase and conversion.

5.2 CONSTRUCTION PHASE

When the design has been completed, tenders for the ship modification would be invited and yard would be selected. We would hope to provide owner's representation during this work and to supervise acceptance trials.

It is probable that special instrumentation will be required and we would expect to be guided in this matter by TDC. German & Milne has a competent instrumentation group capable of designing and providing custom systems.

If German & Milne should be selected as prime contractor for the next phase of this project, it is suggested that a meeting should be held with TDC to decide the program, following which a formal, costed proposal will be made, including an appropriate work statement and time schedule.

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COMPUTER PROGRAM AND PRINTOUT

KEY: A AIR CUSHION BOW IN ICE (Power in this column includes fan power)

B AIR CUSHION BOW IN OPEN WATER

C CONVENTIONAL ICEBREAKER IN ICE

7 CONVENTIONAL ICEBREAKER IN OPEN WATER

F FAN POWER

```
LIST
10  REM  ICEBOW STUDY - C3960
20  REM  REF DECKER,J.L. - APPLICATION  OF AIR CUSHION TECH'Y TO ICEBREAKING
100  DEF FN PWR(X) = ((A2 +  SQR (A2 ^ 2 + 4 * A1 * X)) / 2 / A1) ^ 3
110 M = 1:3048:Z = .004448:Y = .7457:U = .5396 * Y
120  INPUT "SHIP L,B,H,D,DISP ";L,B,H,D,W
130 LE = L / M:BE = B / M:HE = H / M:DE = D / M:WE = W / 1.0163
140  INPUT "CUSHION L,B ";L0,B0
150 L1 = L0 / M:B1 = B0 / M
160 TX = (.04 * B1) ^ 2
165  PRINT "PR00"
170  PRINT "MAX THICK = ";TX;" FT"
180  INPUT "ICE THICK(FT) ";T
183  IF (T > TX) GOTO 900
185  PRINT "PR01": PRINT "       "
188  PRINT "   ICE-BOW STUDY     C3960": PRINT
190  PRINT "L= ";L,"B= ";B,"H= ";H,"D= ";D,"DISP= ";W
192  PRINT "CUSHION L= ";L0,"B= ";B0
198  PRINT "ICE THICK (FT) ";T
200  FOR VK = 1 TO 15 STEP 2
205  PRINT : PRINT "VK= ";VK;" KTS","A","B","C","7","F"
210 R1 = .001149 * (B1 * VK) ^ 2
220 R2 = .00232 * L1 * B1 * VK * SQR (T)
230 R5 = L1 * B1 * T * (.1085 + .0852 * (VK ^ 2 / T) ^ .75)
240 R6 = 68.9 * B1 * T ^ 2
250 K0 = .38 + .012 * LE / DE - .0001 * (LE / DE) ^ 2
260 FR = .2976 * VK /  SQR (LE)
270 A0 = .95 + .15 * (LE / BE - 7)
280 A1 = 6.8 - .2 * (LE / BE - 7)
290 K1 = A1 * FR - A0
300 K = K0 * (K1 < K0) + K1 * (K1 =  > K0)
310 R7 = K * (WE ^ (2 / 3)) * (VK ^ 2)
320 S1 = .2 * BE * HE * VK ^ 2
330 S2 = (179.2 + 28.6 * VK /  SQR (T)) * BE * T ^ 2
340 S3 = 50.4 * BE * T + 313.2 * BE * T ^ 2 + 12.56 * T * VK * BE ^ 1.65
360 RA = R1 + R2 + R5 + R6 + R7 + S2
370 RB = R1 + R7
380 RC = R7 + S3
410  PRINT "RESIST-KN", INT (RA * Z), INT (RB * Z), INT (RC * Z), INT (R7 * Z)
420 BR = BE ^ (2 / 3)
430 A1 = 27.7 * BR:A2 = 1.1373 * BR ^ 2
440 PF = .0792 * L1 * B1 * T ^ 1.5
450 PA =  FN PWR(RA) + PF
460 PB =  FN PWR(RB)
470 PC =  FN PWR(RC)
480 P7 =  FN PWR(R7)
510  PRINT "POWER-KW", INT (PA * Y), INT (PB * Y), INT (PC * Y), INT (P7 * Y), INT (PF * Y)
530  PRINT "KW-HR/KM", INT (PA * U / VK), INT (PB * U / VK), INT (PC * U / VK), INT (P7 * U / V
540  NEXT VK: GOTO 165
900  END
```

1

ICE-BOX STUDY C2560

L= 55	B= 12	H= 3	D= 4.5	DISP= 1408		
CUSHION L= 8.5	B= 12					
ICE THICK (FT)	.75					
VK= 1 KTS	A	0	C	7	F	
RESIST-KN	20	0	55	0		42
POWER-KW	120	0	284	0		
KW-HR/KM	45	0	110	0		
VK= 3 KTS	A	0	C	7	F	
RESIST-KN	17	2	93	2		42
POWER-KW	150	1	434	3		
KW-HR/KM	26	0	70	0		
VK= 5 KTS	A	0	C	7	F	
RESIST-KN	48	7	154	7		42
POWER-KW	211	11	733	11		
KW-HR/KM	22	1	79	1		
VK= 7 KTS	A	0	C	7	F	
RESIS: -KN	61	15	177	14		42
POWER-KW	267	31	1146	30		
KW-HR/KM	22	2	85	2		
VK= 9 KTS	A	0	C	7	F	
RESIST-KN	94	19	237	18		42
POWER-KW	479	123	1695	120		
KW-HR/KM	28	7	101	7		
VK= 11 KTS	A	0	C	7	F	
RESIST-KN	141	90	314	79		42
POWER-KW	837	345	2598	339		
KW-HR/KM	41	16	125	16		
VK= 13 KTS	A	0	C	7	F	
RESIST-KN	210	141	411	140		42
POWER-KW	1460	794	3811	784		
KW-HR/KM	68	32	158	32		
VK= 15 KTS	A	0	C	7	F	
RESIST-KN	384	228	533	227		42
POWER-KW	2482	1604	5085	1585		
KW-HR/KM	89	57	201	57		

2

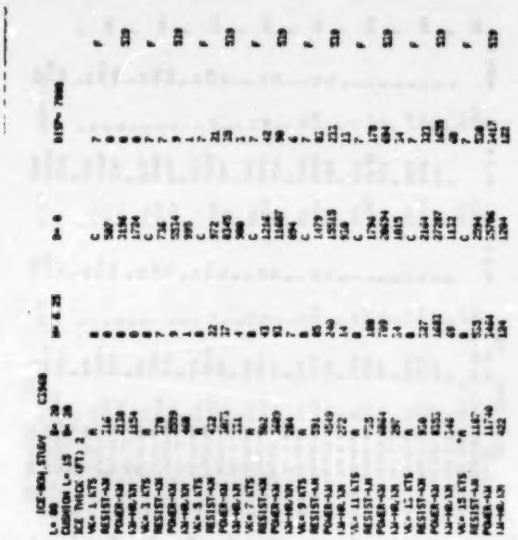
ICE-BOX STUDY C2560

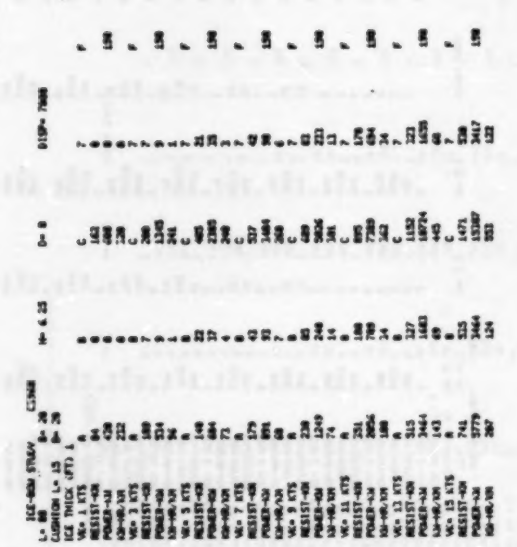
L= 55	B= 12	H= 3	D= 4.5	DISP= 1408		
CUSHION L= 8.5	B= 12					
ICE THICK (FT)	1.5					
VK= 1 KTS	A	0	C	7	F	
RESIST-KN	186	0	172	0		119
POWER-KW	643	0	1861	0		
KW-HR/KM	248	0	572	0		
VK= 3 KTS	A	0	C	7	F	
RESIST-KN	127	2	246	2		119
POWER-KW	881	3	1793	3		
KW-HR/KM	144	0	322	0		
VK= 5 KTS	A	0	C	7	F	
RESIST-KN	156	7	323	7		119
POWER-KW	990	11	2668	11		
KW-HR/KM	186	1	388	1		
VK= 7 KTS	A	0	C	7	F	
RESIST-KN	177	15	482	14		119
POWER-KW	1223	31	3692	30		
KW-HR/KM	94	2	284	2		
VK= 9 KTS	A	0	C	7	F	
RESIST-KN	228	29	498	28		119
POWER-KW	1634	123	5863	120		
KW-HR/KM	90	7	383	7		
VK= 11 KTS	A	0	C	7	F	
RESIST-KN	279	88	618	79		119
POWER-KW	2277	345	6843	339		
KW-HR/KM	111	16	155	16		
VK= 13 KTS	A	0	C	7	F	
RESIST-KN	348	141	744	140		119
POWER-KW	3253	794	9178	784		
KW-HR/KM	125	32	280	32		
VK= 15 KTS	A	0	C	7	F	
RESIST-KN	466	228	992	227		119
POWER-KW	4784	1604	12214	1585		
KW-HR/KM	169	57	439	57		

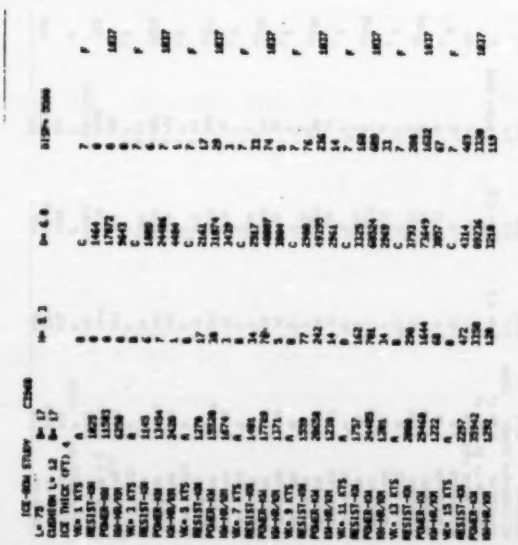
3

ICE-BOX STUDY C2560

L= 55	B= 12	H= 3	D= 4.5	DISP= 1408		
CUSHION L= 8.5	B= 12					
ICE THICK (FT)	2.40					
VK= 1 KTS	A	0	C	7	F	
RESIST-KN	202	0	418	0		253
POWER-KW	2448	0	3914	0		
KW-HR/KM	1121	0	2112	0		
VK= 3 KTS	A	0	C	7	F	
RESIST-KN	324	2	529	2		253
POWER-KW	2948	3	5698	3		
KW-HR/KM	526	0	1025	0		
VK= 5 KTS	A	0	C	7	F	
RESIST-KN	368	7	663	7		253
POWER-KW	3499	11	7730	11		
KW-HR/KM	377	1	834	1		
VK= 7 KTS	A	0	C	7	F	
RESIST-KN	415	15	789	14		253
POWER-KW	4126	31	10014	30		
KW-HR/KM	318	2	771	2		
VK= 9 KTS	A	0	C	7	F	
RESIST-KN	479	30	932	30		253
POWER-KW	5035	123	12817	120		
KW-HR/KM	281	7	768	7		
VK= 11 KTS	A	0	C	7	F	
RESIST-KN	559	88	1091	79		253
POWER-KW	6560	345	16285	339		
KW-HR/KM	287	16	794	16		
VK= 13 KTS	A	0	C	7	F	
RESIST-KN	661	141	1271	140		253
POWER-KW	7949	794	20240	784		
KW-HR/KM	329	32	844	32		
VK= 15 KTS	A	0	C	7	F	
RESIST-KN	787	228	1476	227		253
POWER-KW	10255	1604	25416	1585		
KW-HR/KM	368	57	914	57		







APPENDIX B

PROPOSAL BY HOVERCRAFT CONSULTANTS LIMITED

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HOVERCRAFT CONSULTANTS LIMITED

HCL

Advisory Services to the
Hovercraft, Marine and
Engineering Industries.

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Hythe,
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England.

Tel: HYTHE (0703) 843178.
Telex: 477580 HOVCON G

Mr. P. Markham,
Manager - Special Projects,
German & Milne Inc.,
130 Slater Street, Suite 805,
Ottawa, Ontario,
Canada.

18th January 1982

Dear Mr. Markham,

Air Cushion Icebreaking Ship Project

Following your visit earlier in the month I am now sending you some comments on our discussions and an indication of the extent to which HCL could assist with the cushion technology of icebreaking projects.

I should emphasise that the skirt and cushion design will depend on the geometry chosen for the icebreaking air cushion platform. For this reason I am suggesting that our proposal should be in two parts.

Our Phase I report would comment on the layouts proposed by German & Milne including:

1. Comment on systems suggested by German & Milne, with particular reference to the feasibility of providing an effective skirt system, performance, maintainability, service life, spray, ballasting (of platform and/or ship), lift air supply and cushion/ship interface.

2. Comment on water curtains.

3. Suggest alternative layouts or concepts.

4. Comment on the size, depth and shape of the cushion to meet the requirements laid down.

Our Phase II report would be prepared after a preferred system had been selected. It is recognised that the decision will have been influenced to some extent by HCL's Phase I but German & Milne, in consultation with the Contracting Authority, will make the final decision paying special attention to local requirements and the particular tasks required of the initial application. Phase II would, therefore, address the following matters for the chosen system:

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HCL

1. Comment on selected cushion planform, depth and pressure range with suggestions for the values of parameters not completely defined.

2. Review cushion/ship seal systems and other interface topics.

3. Provide conceptual skirt design with material recommendation.

4. Design, construct and test a simple skirt model.

5. Comment on proposed deployment and retraction system.

6. Suggest methods of skirt maintenance, spares holding and equipment needed.

7. Derive lift system specification including air supply arrangements.

8. Suggest ballasting arrangements and indicate effect on ship's trim.

9. Indicate cushion induced loading systems, including heave, pitch and roll behaviour.

10. Propose spray suppression systems.

11. Review methods for improving icebreaking performance.

The cost of carrying out Phase I would C$10,550 while the cost of Phase II would be C$15,400. If required, HCL would be prepared to provide drawings suitable for the manufacture of the skirt under its supervision in the UK for a price to be agreed.

HCL's normal terms of business are for a fifty percent down payment on receipt of instructions followed by the remaining fifty percent on delivery of the report. In this way risks and interest on outstanding fees are equitably shared.

I hope that HCL is able to participate in this study. As you will know from the prospectus, I and my staff have a great deal of experience in all types of air cushion and skirt systems. HCL has recently carried out a detailed feasibility study for a US oil company wishing to move oil drilling rig components over water, and over solid ice as well as in the icebreaking mode.

CA1 DTC 801 82 C53 c.2

Description				Stock No. - *Nº de nomenclature*
U of I - *U de D*	Unit Price - *Prix unitaire*	Minimum	Maximum	Location - *Lieu*

Date	To/From - *À/De*	Ref. No.-*Nº de ref.*	Issues - *Sorties*	Receipts - *Entrées*	Balance - *Solde*

Government of Canada / Gouvernement du Canada

STOCK RECORD
FICHE DE STOCK

CGSB STANDARD FORM 139
FORMULE NORMALISÉE 139 DE L'ONGC
7540-21-870-7438